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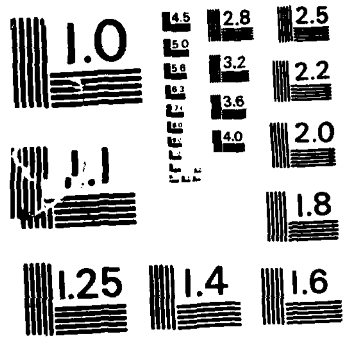

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INSTITUTE FOR PHYSICAL SCIENCE AND TECHNOLOGY

ANNUAL SUMMARY REPORT

to the

OFFICE OF NAVAL RESEARCH

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on

Contract N00014-85-K-0436

Acceleration of Ions and Electrons by Wave-Particle Interactions

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UNIVERSITY OF MARYLAND

CONTENTS

I. HIGHLIGHTS OF RESEARCH ACTIVITIES

In this report, we briefly describe the key results and major accomplishments of the research carried out at the University of Maryland under the auspices of the Office of Naval Research Contract N00014-85-K-0436.

A. Overview

The research program is divided into four tasks.

1. Application of kinetic cross-field streaming instabilities to laboratory experiments.

2. Electromagnetic electron-cyclotron instability excited by hot electrons with a loss-cone distribution.

3. Induced emission of electromagnetic radiation near the second harmonic of the plasma frequency.

4. Effects of an electrostatic instability on the induced emission of electromagnetic radiation near $2\omega_e$.

B. Summary of Research Accomplishments

We now summarize the research results achieved. Detailed reports on each problem are given in the published papers.

1. **Applications of kinetic cross-field streaming instabilities to laboratory experiments** (E. H. da Jornada, J. D. Gaffey, Jr., and D. Winske, Phys Fluids 28, 611, 1985).

In a recent paper[1] we have investigated the kinetic cross-field streaming instability[2] which is excited by an ion drift across the magnetic field and electron temperature anisotropy, $T_{e\perp} > T_{e\parallel}$. We have found that the usual low-β modified two-stream instability[3] is modified by finite-β effects[2] and enhanced by the electron temperature anisotropy[1] Quasilinear theory predicts, and computer simulations have verified, that this instability results in significant heating of the electrons and ions[4]

We have extended the theory of cross-field streaming instabilities to the parameter regime of the Tandem Mirror Experiment (TMX) with neutral beam injection[5] The cross-field ion drift, as well as the electron

thermal anisotropy, provides the free-energy for several instabilities. Three instabilities have been found to occur: an obliquely propagating electromagnetic, lower-hybrid instability (EMLHI), an obliquely propagating ion-ion streaming instability (IISI), and a nearly perpendicular propagating, modified two-stream instability (MTSI). The latter two modes (IISI and MTSI) are electrostatic and their real frequencies are insensitive to the electron temperature anisotropy. The EMLHI and MTSI are the low-β limits of the kinetic cross-field streaming instability.[1] The major conclusions of our study are:

a. The EMLHI is highly kinetic for small values of the drift velocity V_0.

b. The IISI has the largest growth rate when the ratio of the drift to the background ion thermal velocity $V_0/v_{i0} \lesssim 4$.

c. The MTSI has the largest growth rate when $V_0/v_{i0} \gtrsim 4$.

d. Thus, for the present conditions in TMX, the IISI has the largest growth rate; however, when more energetic neutral beams become available, the MTSI may become the dominant instability.

2. **Electromagnetic electron-cyclotron instability excited by energetic electrons with a loss-cone distribution** (H. K. Wong, C. S. Wu, and J. D. Gaffey, Jr., Phys. Fluids <u>28</u>, 2751, 1985).

An electromagnetic electron-cyclotron instability associated with a loss-cone distribution of energetic electrons has recently been investigated extensively by the space physics community[6-10] as a source mechanism of the auroral kilometric radiation (AKR).[11-19] It has also been suggested that this instability may occur in some laboratory experiments, such as TMX and EBT. A special case of the electron-cyclotron instability excited by a loss-cone distribution of energetic electrons has been studied recently.[20] The analysis is restricted to the special case of radiation propagating parallel to the applied magnetic field ($k_\perp = 0$) and, moreover, emphasis is placed on the limit $k_\parallel \to 0$. We have generalized the theory to treat an arbitrary direction of propagation and, in addition, a background of cold electrons is included. The major conclusions of our study are:

a. The electron-cyclotron instablity can occur at all angles of propagation for a wide range of parameters.

b. In general, the instability for nearly perpendicular propagation is more serious than that for parallel propagation.

c. The peak of the growth rate, maximized over k, increases with temperature T, and for large T occurs at finite k, rather than at k = 0.

d. The range of unstable values of ω_e/Ω_e broadens as T increases.

e. The instability can be suppressed by the presence of a sufficiently large population of cold electrons if T is not too high.

Recent observations[21] indicate that this instability does occur in TMX.

3. **Induced emission of electromagnetic radiation near the second harmonic of the plasma frequency** (C. S. Wu, G. C. Zhou. amd J. D. Gaffey, Jr., Phys. Fluids 28, 846, 1985).

The loss-cone cyclotron instability has recently been extended to the case of electrons with a hollow-beam distribution.[22,23] The study was motivated by the idea that the mechanism may also be applicable to the theories of some solar radio emission processes. However, the discussion in Refs. 22 and 23 is limited to cases in which the plasma frequency ω_e is comparable to the electron-cyclotron frequency Ω_e. In many important astrophysical problems, the radiation processes occur in regions where $\omega_e^2 \gg \Omega_e^2$. For example, in the source region of type II and III solar radio bursts, it is usually believed that $\omega_e^2 \gg \Omega_e^2$. Thus, it is necessary to extend the treatment of the electron-cyclotron instability to the high-density, weak-magnetic-field regime. We have re-examined the hollow-beam excited instability with $\omega_e^2 \gg \Omega_e^2$ for this reason. The major conclusions of our study are:

a. The presence of a hollow-beam of moderately relativistic electrons can amplify unpolarized electromagnetic waves with frequencies near twice the plasma frequency.

b. As the electron energy increases, the real frequency, corresponding to the peak of the maximum growth rate, shifts to values higher than $2\omega_e$.

c. The principal source of the free-energy which drives the instability is the ring feature of the distribution, rather than the beam.

4. **Effects of an electrostatic instability on the induced emission of electromagnetic radiation near $2\omega_e$** (S. Kainer, X. W. Hu, J. D. Gaffey, Jr., and C. S. Wu, Phys. Fluids 28, to be submitted, 1985).

It is well known that a hollow-beam distribution of electrons is also unstable to Langmuir waves, which have much larger growth rates than the electromagnetic instability. Linear theory predicts that for a cold hollow beam the maximum growth rate for the electrostatic instability occurs for waves propagating parallel to the ambient magnetic field[2,4] and thus the beam feature of the distribution is the primary source of free-energy for the electrostatic instability, whereas the ring is the primary source of free-energy for the electromagnetic instability. However, for oblique propagation quasilinear diffusion in velocity-space resulting from the presence of the electrostatic instability may inhibit the growth of the electromagnetic instability, since both waves may be excited by the same portion of the distribution function. To examine the nonlinear development of the instabilities, we have performed numerical simulations using an electromagnetic relativistic particle code. The major results of our preliminary study are:

a. The electromagnetic instability is modified, but not suppressed, by the presence of the electrostatic instability.

b. For propagation at large angles with respect to the magnetic field, the electrostatic instability is also excited by the ring feature of the distribution and is modified strongly by the presence of the electromagnetic instability.

c. Further study of nonlinear effects is necessary in order to predict the growth rates and saturation levels of the instabilities because of the strong nonlinear competition between the electrostatic and electromagnetic modes.

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II. PUBLICATIONS/PATENTS/PRESENTATIONS/HONORS

A. Papers Submitted to Refereed Journals (not yet published)

1. Effects of an electrostatic instability on the induced emission of synchrotron-maser radiation near $2\omega_e$, S. Kainer, X. W. Hu, J. D. Gaffey, Jr., and C. S. Wu, Phys. Fluids 28, submitted (1985).[1]

B. Papers Published in Refereed Journals

1. Effect of electron thermal anisotropy on the kinetic cross-field streaming instability, S. T. Tsai, M. Tanaka, J. D. Gaffey, Jr., E. H. da Jornada, C. S. Wu, and L. F. Ziebell, J. Plasma Phys. 32, 159 (1984).[2]

2. Instabilities excited by an energetic ion beam and electron temperature anisotropy in Tandem mirrors, E. H. da Jornada, J. D. Gaffey, Jr., and D. Winske, Phys. Fluids 28, 611 (1985).[2]

3. Induced emission of radiation near $2\omega_e$ by a synchrotron-maser instability, C. S. Wu, G. C. Zhou, and J. D. Gaffey, Jr., Phys. Fluids 28, 846 (1985).[1]

4. Electron-cyclotron maser instability caused by hot electrons, H. K. Wong, C. S. Wu, and J. D. Gaffey, Jr., Phys. Fluids 28, 2751 (1985).[3]

C. Books (and Sections thereof) Submitted for Publication

Not applicable

Other partial support provided by:

[1] NASA.

[2] NASA and CNPq.

[3] NASA and NRC.

D. Books (and Sections thereof) Published

Not applicable

E. Patents Filed

Not applicable

F. Patents Granted

Not applicable

G. Invited Presentations at Topical or Scientific/Technical Society Conferences

Cyclotron-Maser Instabilities: Auroral Kilometric Radiation (AKR) and Other Applications; C. S. Wu, invited talk presented at the 26th Annual Meeting of the Division of Plasma Physics of the American Physical Society held in Boston, MA, October 29 - November 2, 1984!

H. Honors/Awards/Prizes

Professor C. S. Wu was elected a Fellow of the American Physical Society in October, 1984

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